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A REVIEW OF CURRENT DECK LANDING TECHNIQUES

by

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SECURITY INFORMATION

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1 Introduction

Deck landing techniques have been the subject of considerable discussion and experiment in the last two or three years. A change in technique has been introduced into the Royal Navy, in the interests of standardisation, and modifications to this new technique have been made, both deliberately and unwittingly. Accordingly it was considered advisable to collect together such information as was available on the variety of techniques that have been used, in an attempt to show whether any one of them was superior to the other, or to suggest further lines for investigation. The elusive optimum technique is considered to be that which makes the least demands on the pilot's skill and judgement and which is the least likely to result in damage to the aircraft due to human errors both on the part of the pilot and the Deck Landing Control Officer.

The ultimate test of a particular technique is the accident rate resulting from its use. Obviously our assessment of the various techniques cannot be made on this expensive basis at this stage, so that attention is directed to those features which are believed to leave excessive room for the errors of judgement which are the primary cause of the great majority of deck landing accidents.

2 The evolution of current deck-landing techniques

A deck-landing technique may be defined, for comparative purposes, as the variation of height with distance during the last, say, 1000 feet of the approach to the carrier. This variation, which is usually represented diagrammatically as the side elevation of the approach path relative to the carrier, is largely under the control of the pilot and the deck landing control officer (D.L.C.O.). The approach airspeed, V_A, which may be expressed in terms of the engine-on stalling speed V_{SE}, and the impact vertical velocity at touch-down, are to some extent dependent variables, in that the pilot is not free to vary them at will.

Attention is therefore first directed to the various types of approach path that have been used during the past 3-4 years. Information and discussion on airspeeds and vertical velocities, etc., appear later.

2.1 The pre-1949 era

Prior to the introduction of the so-called standard deck-landing technique, Royal Navy pilots used what is commonly called the "Old British" technique. This technique was not rigidly defined, and could, in fact, be varied somewhat to suit a particular aircraft type. There were, of course, additional variations on a given type due to the personal likes and dislikes of a particular pilot/D.L.C.O. combination, especially when the pilot and D.L.C.O. knew each other well.

This technique was used, for example, by the Seafire, and Fig.1 records the mean, maximum and minimum height of the wheels above deck level as a function of the distance of the aircraft astern of the carrier. The mean line may be treated as a typical approach path in this group of 10 landings by one pilot on H.M.S. "Pretoria Castle" in 1944[1].

This type of approach is characterised by a fairly steep, steady descent aimed at a point just forward of the round-down. In this particular example, the glide angle was around 4 or 5 degrees to the horizontal, relative to the carrier deck, although, as stated above, a different pilot or aircraft might have produced a slightly different mean angle. Not more than 1 second before touch-down, the D.L.C.O. gave the "out" signal for the pilot to close the throttle, by which time a partial check had been made, to reduce the vertical velocity. This check

was more often the result of a small application of power, following a "go-higher" signal from the D.L.C.O., rather than a backward movement of the stick, the latter being likely to lead to float. Every effort was made to touch down with the tail well down in the 3-point attitude, to reduce the risk of an aerodynamic bounce. The aim was to achieve this attitude before arrival over the deck, to avoid the necessity of a last-minute rotation of the aircraft in pitch.

With this type of approach, it was relatively easy for the D.L.C.O. to judge the point of arrival on the deck, and he was able to exercise control almost up to the point of touch-down. Impact vertical velocities were low (about half the value accepted as normal at present) and the trim change on closing the throttle was relatively unimportant.

It was, however, difficult for the pilot to judge where to start this final steady descent, and this led to inconsistent approach paths. The final check tended to produce touch-down points rather far up the deck or, alternatively, the clearance over the round-down was low which could be dangerous in rough weather. Further, this check, which was made essential by the then universal tail wheel type undercarriage with low design vertical velocity, required fine judgement by the pilot. If overdone, and particularly if the elevator was used in the process, it led to float over the wires, while if the aircraft touched down on its main undercarriage only, an aerodynamic bounce or damage to the undercarriage was likely. The accident rate on Seafires, largely due to these causes, was very high.

Finally, this type of approach required careful control of the approach airspeed. If the margin over the stall was too low, the pilot was unable to perform the desired check without danger of stalling, and the nose-up attitude made the already appalling view even worse. If the speed was high, then bounce or float was likely.

While the choice of the Seafire as an example may be criticised on the grounds that it was not a typical aircraft of the pre-1949 era, it did at least typify the difficulties and shortcomings of the old system.

2.2 The "standard" technique in the U.S. Navy

Confidential Admiralty Fleet Order No.211 dated 1st July 1949 introduced into the Royal Navy the deck-landing technique already used by the U.S. Navy. The description of the technique contained in this Order specifically required the aircraft to make its final straight approach to the deck in level flight at a height of 15-20 feet above the deck. The "cut" signal was to be given while in level flight, of necessity some distance aft of the round-down. Thereafter, the pilot had to make his own landing.

The technique already used in the U.S. Navy is described first, and is illustrated in Fig.2, which gives the mean height of the wheels above deck level as a function of distance astern of the carrier, during landings by F9F-Panthers (single-jet fighters) and by F8F-Bearcats and F4U-Corsairs (both propeller-driven piston engined fighters), aboard U.S.S. Midway in 1950.

These records show that during these landings there was seldom any level portion in the final approach, and the mean path was at an angle of just over 1° to the horizontal. The "cut" signal was usually given after the initial shallow glide path had been steepened for the final descent on to the deck. The mean glide angle at the "cut" point was over 3°, while at touch-down it was over 6°. Table I gives further details of these landings, which were all recorded in fair weather. The height over the round-down on the Panther, for example, would need to be increased if the deck were pitching.

Lest it be implied that the pilots and D.L.C.O.'s on "Midway" had deliberately and unofficially modified the prescribed technique, it is emphasized that it is very difficult to judge between a level path and one inclined at 1° to the horizontal. It may be that the changing foreshortened view of the carrier deck as the aircraft turns into line with the ship gives the pilot the impression that he is flying level while in fact he is slowly descending.

2.3 The "standard" technique in the Royal Navy

Early reports[2] on the application of the new technique to British naval aircraft were fairly enthusiastic. The "level" approach was found to be easier to judge. Very few throttle movements were necessary, most of the height corrections being made with elevator. The slightly higher engine power required improved the baulked-landing behaviour, and a "wave-off" could be given later than with the British technique. It was considered that the early "cut" was an advantage in that it gave the pilot more time to make final corrections before the touch-down, which, it was claimed, was "surprisingly gentle".

It was, and still is, agreed that, in some ways, the D.L.C.O. now has an extra share in the responsibility for making a safe landing. Although most of the signals which he gives to the pilot on the approach now convey information, rather than instructions, much depends on his judgement of the correct position at which to give the mandatory "cut" signal. A badly timed signal, if obeyed by the pilot, can have serious consequences, particularly if the aircraft were in level flight at the time.

Approach paths have been recorded for a number of aircraft using the "standard" technique during carrier deck-landing trials on H.M.S. "Illustrious". A selection of curves showing the mean height of the wheels above the deck as a function of distance from the carrier is given in Fig.3. Also given is the mean approach path for Sea Vampire aircraft landing on H.M.S. "Theseus" in operational conditions, indicating that pilots making trial landings were using a technique very similar to that used in Service.

Compared with the mean paths produced by the pilots on the U.S.S. "Midway" (Fig.2), these paths are of the same general shape, but are somewhat steeper initially, at a glide angle of about 2° to the horizontal. The increase in glide angle in the region of the "cut" point is less marked, in fact, the glide angle increases continuously during the final 2-300 yds of the approach.

Accumulated experience has revealed a number of features of the "standard" technique which are regarded as unsatisfactory. The D.L.C.O. has to decide on a suitable "cut" point, judged on the aircraft's speed, height and rate of descent. This point is decided largely by guesswork, and since he dare not err on the early side, there is a tendency to give the "cut" after the optimum point has been passed. Thereafter, the pilot has to complete the landing unaided, with engine off, from a point which is some distance astern of the round-down, but which may be too near the desired touch-down point, considering the height still to be lost. The change in trim on closing the throttle is of great importance. If there is a nose-up trim change the aircraft is likely to touch down further up the deck than the D.L.C.O. intended. If the trim change is nose-down, there may be a considerable increase in rate of descent, necessitating a well-judged check and ample elevator power, while on a propeller driven aircraft, elevator power may be seriously reduced on closing the throttle (e.g. Fairey GR17/45). The "last-minute" check to reduce a high rate of descent, may do no more than produce an exaggerated tail-down attitude at touch-down, leading to damage to the rear end of the aircraft. A wide range of touch-down attitudes is therefore likely.

The effect of the "standard" technique on impact vertical velocities (on which information is given in Table II) is not clear-cut. It is fairly certain that high impact vertical velocities will result if the "cut" is taken in level flight, necessitating a rapid increase in rate of descent, with insufficient time to produce a check. The higher the rate of descent at the "cut", the less the change that is required, and high impact vertical velocities are less likely. We may therefore expect that, insofar as the techniques described above are typical of Service practice, the Royal Navy's interpretation of the technique is less severe on the undercarriage than that used by the U.S. Navy.

2.4 Modifications to the "standard" technique

In an attempt to overcome some of the undesirable features of the prescribed standard technique while retaining the good points, a technique which is a compromise between the standard and the original British techniques has been used on a number of occasions by pilots of the A&AEE during deck landing trials. This new technique, which in fact, seems to correspond more closely to the Old British than to the standard technique, is best illustrated by the mean approach paths shown in Fig.4. Compared with the paths given in Fig.3, the modification has steepened the initial path to around 4°, and there is now no noticeable increase in glide angle in the region of the round down. Over the final 300 feet, the path is above that recorded for the Seafire (Fig.1).

The advantages claimed for this type of approach are detailed in the reports of the carrier trials on these three aircraft[3,4,5]. It has made the most favourable impression on pilots flying the Venom and Fairey GR17/45, where, with a forward C.G. position, there was said to be insufficient elevator power to achieve the desired attitude and check of the rate of descent from the standard approach. Using the modified technique, only comparatively small changes in attitude and rate of descent were needed. With the late "cut", the trim change on closing the throttle was of less importance, and the previously marginal or inadequate elevator power became satisfactory.

In addition, the D.L.C.O., who was moved forward so as to be ahead of the aircraft up to the point of touch-down, was now able to control the aircraft almost on to the deck, reducing the scope for errors of judgement in the final stages.

In Table II, results of the analysis of landing records using the standard and modified techniques are given. The chief difference between the two techniques as revealed by these figures, is a reduction in impact vertical velocity for the Fairey and Blackburn GR17/45 aircraft using the modified technique. On the Sea Venom the higher mean impact vertical velocity attributed to lack of elevator power with the forward C.G. position, was counteracted by the change to the modified technique.

For easier comparison, the four typical forms of deck-landing approach path are plotted together on Fig.5, which also shows the mean position of the aircraft when the "cut" signal was given.

3 Approach airspeeds - future trends

The mean approach airspeeds, and the standard deviation about the mean, are given in Table II for the British aircraft. There appears to be a small reduction in the mean approach airspeed over the final 10 seconds of the approach when the modified technique is used, but this is probably not large enough to be significant.

No stalling speed measurements are available except on the Attacker, for which the mean approach airspeed is 1.16 times the engine-on stalling

speed. Partial glide tests show that this approach airspeed is 97% of the minimum drag speed and suggest that even at the lowest airspeeds used, no difficulty should arise due to poor control of airspeed or rate of descent, according to the criterion proposed in Ref.6.

For evidence on the trend of the ratio of approach airspeed to stalling speed, use is made of the results of a series of deck-landing trials in which the speed of the aircraft relative to the carrier was increased to nearly 110 knots, in anticipation of the relative speeds expected with future naval aircraft and arrester gears.

Fifty-one approaches and touch-downs using the "standard" technique (with no arrester gear or barrier) were made on H.M.S. "Illustrious" by Sea Vampire Mk.20 aircraft. The wind speed over the deck was reduced in stages till eventually the approaches were made down-wind. The pilots were asked to note any difficulty which became more pronounced as the relative speed increased. After each touch-down, the aircraft took-off again immediately.

Conditions were slightly artificial for two reasons. Since the landings were not arrested, the pilot had to be ready to apply full throttle for take-off as soon as he had touched-down. This may well have affected the procedure following the "cut". The throttle was not always fully closed on receipt of the "cut" signal; in some instances it was not moved at all till after touch-down. These landings were made basically by use of elevator, and the touch-down points tended to be rather far up the deck, because of the large forward stick movements required.

Secondly, since high closing speeds could only be simulated by decreasing the wind speed over the deck, the turn-in from the down-wind leg had to be started further aft than usual, in order that the turn could be completed before the round-down was reached. Although possibly of secondary importance, this enforced change in the landing "pattern" was an undesirable feature.

The measured final approach airspeeds have been converted into speed margins over the corresponding engine-on stalling speeds (V_A/V_{SE}) and are presented in Fig.6 as a function of the relative speed. In spite of the scatter, a definite upward trend may be observed. The rate of increase indicated by the mean line is compared with a proposed method of estimating the mean speed margin for any aircraft[6], which is based largely on the reported difficulty of correcting errors of line at increasing relative speeds. The proposed rate of increase would, theoretically, give a constant effective margin of safety over the stall during the S-turns necessary to correct for misalignment with the deck. The observed rate of increase of V_A/V_{SE} is about half the proposed value. The pilots commented on the increased difficulty of correcting line errors, due to lack of time, and to the fact that the D.L.C.O. could not detect and signal these errors before the pilot had himself taken corrective action. However, they did not report that the airspeed was deliberately increased at the higher closing speeds to overcome this. The reported lack of response and effectiveness of ailerons and rudder became increasingly embarrassing as the relative speed increased, and this may have prompted the observed small increase in speed margin over the stall. The proposed rate of increase (Fig.6) appears to be adequate for the Vampire.

4 The final phase - "cut" to touchdown

4.1 "Cut" position and its effect on the touch-down

It has been stated (Section 2.3) that much depends upon the D.L.C.O.'s assessment of the correct position at which to give the "cut" signal.

From this it might be inferred that there should be some correlation between the "cut" position and, for example, the impact vertical velocity. In fact, no connection has been found between the impact vertical velocity and the "cut" position, denoted by the height of the aircraft above deck level. American studies[7] have arrived at the same conclusion. The implication is that the pilot adapts his "post-cut" technique to ensure that he arrives at the desired region on the deck with a reasonable vertical velocity, irrespective of when he receives the "cut". We should expect this to be relatively easier when the aircraft already has a positive rate of descent at the "cut" point. The modified standard technique is therefore an improvement in that the "cut" may be given later, at a point where the D.L.C.O. is better able to judge the touch-down position on the deck, and from which the pilot can complete the landing in a relatively short time.

Tables I and II show that, at normal relative speeds of up to 70-75 knots, the "cut" position, using the standard technique, is 100-150 feet aft of the round-down, at a height of 15-20 feet above the deck. With the modified technique, the "cut" is given at around 30 feet aft of the round-down, when the height is 10-15 feet.

At higher relative speeds (up to 105 knots), the "cut" was given progressively further aft, while the touch-down points moved gradually further forward of the round-down. This effect is illustrated in Fig.7. For clarity, the relative speeds for the Vampires have been averaged in 10-knot groups, covering the range 70-80 kts, 80-90 kts, 90-100 kts and 100-110 kts. Mean points are also shown for a number of other aircraft additional to the Vampire results.

Although, during the Vampire high closing speed trials, the "cut" was sometimes given (but not necessarily acted upon) when the aircraft was as much as 400 feet or more aft of the round-down, there appears to be no connection between the impact vertical velocity and the "cut" position defined in this way. The records show that the horizontal distance between the "cut" and touch-down points was roughly proportional to the relative speed, so that about the same time was available for the descent on to the deck from the "cut" height.

The conclusion is that the "cut" signal merely indicates to the pilot the point at which he is to take over full responsibility for completing the landing. When the "cut" is given far astern - for example, when the relative speed is high, or when a true horizontal approach is being made - the pilot has more opportunity for making errors, and the D.L.C.O. cannot be certain that a successful landing will follow. Further, his difficulty in judging the correct instant at which to give the "cut" has obviously increased, and the pilot may have a natural aversion to closing the throttle while he can still see a wide expanse of sea between him and the carrier.

4.2 Condition of aircraft at "cut", and effect on touch-down

The rate of descent in the final stage of the approach has a marked effect upon the choice of the "cut" position, and might be expected to have a bearing on the final touch-down.

The condition of the aircraft at the "cut" point may conveniently be denoted by the ratio of the height above the deck to the instantaneous rate of descent, i.e., in terms of a fictitious "time-to-go" before touch-down. This is the time that would elapse before touch-down if there were no further change in the rate of descent.

The actual time between "cut" and touch-down was between 2 and 4 secs for most of the landings examined. Clearly, if the "time-to-go" at

the "cut" exceeds this, an increase in rate of descent is indicated, and the amount of this increase is a measure of the change in flight condition necessary to complete the landing. On some aircraft, part or all of the change might arise automatically from the trim change on closing the throttle. In other cases (e.g. for the Vampire high closing speed trials), the change was produced almost entirely by elevator.

Fig.8 shows that, as expected, there is a tendency towards large increases in rate of descent between "cut" and touch-down when the "time-to-go" at the "cut" exceeds about 4 seconds. These results were obtained during the Vampire high closing speed trials. They show that increases in rate of descent of up to 10 ft/sec were required when the "cut" was taken high above the deck, in near-level flight. At the average glide angle recorded at the "cut" point, the "time-to-go" is such that only a small increase in rate of descent is necessary. A moderate rate of descent at the "cut" therefore reduces the amount of control movement necessary to complete the landing and the room for error in making those movements.

4.3 The "post-cut" manoeuvre - piloting technique

Following the "cut", a nose-down trim change is normally required, except when, as with the original British technique, the flight path is already sufficiently steep to ensure a reasonably early touch-down. Unless the trim change with power is sufficient, a forward movement of the stick is needed, and therein lies one source of pilot error. It is believed that there may be a tendency to over-do this manoeuvre and dive for the deck when the deck is obstructed by barriers and the forward aircraft park. This tendency may be further encouraged by the D.L.C.O. giving a late "cut" (see Section 2.3). In such cases, an excessive rate of descent may develop, which the pilot will try to reduce by a backward stick movement before touch-down.

This attempt to reduce the impact vertical velocity by means of the flare is a fairly common feature of the landings made by the techniques so far discussed. Its effectiveness is doubtful, however, particularly in those cases where a reduction is most needed. If a high rate of descent is generated just before the touch-down, the aircraft will arrive on the deck before any appreciable reduction can be made. Suppose, for example, that the speed margin over the stall is such that a lift/weight ratio of 1.2 can be used during the flare. If the initial rate of descent is 20 ft/sec, then almost 15 feet of height will be lost in reducing this rate to 15 ft/sec. If, however, the initial rate of descent was 10 ft/sec, this could be halved in only 6 feet of height from the point at which the full L/W ratio was available. In general, the higher the rate of descent, the smaller is the reduction in that rate that can be produced in a given height before touch-down.

This fact is difficult to demonstrate experimentally without elaborate instrumentation. From the available data, however, some information may be obtained on the occurrence of "last-minute" attempts at reducing the vertical velocity. Such attempts will result in rapid increases in incidence just before touch-down, and will manifest themselves as increases in aircraft attitude. The resulting differences in vertical velocity of the main and of the nose or tail wheels are a measure of the rate of change in attitude, which will be roughly the same as the rate of change of incidence, changes in glide angle being relatively small.

In Fig.9, the difference in the vertical velocity of the main and of the nose or tail wheels is plotted against the impact vertical velocity of the main wheels. These vertical velocities are mean values over the final 0.25 second period before the main wheels touch the deck. Although occasionally an arrester wire may be engaged in this interval (but rarely

any earlier) no sign of any change in the vertical velocity of the nose or tail wheel due to this cause was observed.

The diagrams of Fig.9 are interpreted only as suggesting that the higher impact vertical velocities are associated with more rapid nose-up pitching angular velocities, and that these angular velocities result mainly from a rapid "last-minute" increase in incidence, i.e. an attempt to flare. It is fairly clear, from theoretical considerations, that such attempts can have had little effect on the vertical velocity.

A further argument against the use of the flare technique is that it leads to a wide range of attitudes at touch-down. On some aircraft, it can lead to an undesirably tail-down attitude which may damage the rear end of the (tricycle) aircraft. On an aircraft with a long sting-type hook, it will encourage the engagement of an arrester wire before touch-down, which may lead to excessive nose-wheel impact loads. Finally, it is a manoeuvre which, if overdone, can lead to floating into the barrier. There is therefore a strong case, as recommended in Ref.8, for eliminating the flare, the aircraft being rotated to the correct touch-down attitude as soon as possible after the "cut", and held at that attitude until contact with the deck is made. Since an appropriate rate of descent must be established at the same time, the process will be simplified if the aircraft already has a positive rate of descent at the "cut".

5 Further developments in deck landing technique research

The high closing speed trials with Vampire aircraft, mentioned in Section 3, underlined the shortcomings of the D.L.C.O. as a means of assisting the pilot when the relative speed is high. By the time the D.L.C.O. had decided that some correction was necessary, signalled it to the pilot and the pilot reacted to it, the situation was likely to have changed. The D.L.C.O.'s chief usefulness was in giving the "cut" or wave-off signals, and the early "cut" required from a standard or shallow approach left room for error on the part of both pilot and D.L.C.O.

These difficulties point to the desirability of some automatic aid for the pilot, if only to eliminate the time lag between detection of an error by the D.L.C.O. and its correction by the pilot. Whether the error information is passed to the pilot by radio or optical means, or whether it is fed directly into an automatic pilot, the solution to the problem will be simplified if a straight descending approach is used. This approach would be at a constant rate of descent that could be safely absorbed by the undercarriage, and along a path giving adequate clearance over the round-down with a reasonable touch-down point. There need be no "cut" and no flare.

The elimination of the flare has already been tried and recommended[8]. Elimination of the "cut" (treated as a signal to close the throttle) is also possible, as has been shown in carrier deck landing trials in connection with an angled deck scheme[9]. These trials showed, however, that it was much easier to land without closing the throttle from a descending as opposed to a standard approach since much less elevator movement was needed to complete the landing.

The combined "no-cut, no-flare" technique has been assessed in recent deck-landing trials on H.M.S. Illustrious. No D.L.C.O. was used, and the correct glide path was indicated to the pilots of the Vampire aircraft by an optical system. This consisted of a large mirror, 8 ft high and 4 ft wide, facing aft, in which was reflected a bar of light from lamps shielded from the direct view of the pilot. When viewed from anywhere on the correct glide path, the bar of light appeared exactly half-way up the mirror. If the aircraft climbed above the correct path,

the bar of light was seen above the centre of the mirror, while if the aircraft got too low, the bar appeared below the centre. The system thus gave a continuous indication of the amount and direction of the height error.

The mirror, which was slightly curved in horizontal section (to allow the reflection to be seen when the mirror was off to one side of the flight path) was erected with its major dimension approximately vertical on the starboard deck edge, 160 ft from the round-down. Gyro-stabilising equipment, essential for compensating for the pitching of the flight deck, was not available for these preliminary trials, some of which were done while the deck was pitching almost $\pm\frac{3}{4}$ degrees.

Preliminary analysis of the records indicates that this approach technique is perfectly feasible in fairly calm weather, even though the optical path which the pilot was following was not then stabilised. Assistance could be given to the pilot from a range of 2 miles down to the touch-down, which was, if anything more gentle and consistent than when using a conventional technique.

A number of the recorded approach paths are shown graphically in Fig.10. There appears to be a tendency for the aircraft to get appreciably low over the round-down. This may be due partly to the known existence of a region of down-draught just aft of the round-down on "Illustrious", and partly to a desire on the part of the pilots to engage an arrester wire earlier than the one for which the system was set up.

The choice of the position and inclination of the glide path is a matter of compromise. Fig.11 shows the possible combinations of the three variables, (a) round-down clearance, (b) impact vertical velocity and (c) position of touch-down point, for three classes of aircraft having relative speeds of 60 knots (e.g. the anti-submarine aircraft on the Light Fleet carrier), 75 knots (e.g. the present-day fighter on the Fleet carrier) and 105 (e.g. a future fighter on the modernised carrier). The clearances and vertical velocities apply only when the deck is not pitching. With the beam stabilised for rough-weather operation, a ±10 ft movement of the stern could alter the round-down clearances by the same amount, and could change the velocities normal to the deck by 4, 5 and 7 ft/sec for the three classes of aircraft respectively, due to the inclination of the deck. The vertical movement of the deck has little effect on the vertical velocities since the touch-downs are assumed to be near the null point of the pitching oscillation.

If we aim for a minimum clearance of 5 feet over the round-down when the stern is moving through ±10 ft about its mean position, we require a clearance of 15 feet over the "rest" position of the round-down. We further arbitrarily choose limiting touch-down points of 150, 175 and 200 feet forward of the round-down. These two limitations can be met with mean impact vertical velocities of 10, 11 and 13 ft/sec on the three classes of aircraft considered. These vertical velocities are 60-65% of the assumed undercarriage proof vertical velocities of 16, 18 and 20 ft/sec respectively, and still allow for the possible increases in velocity normal to the deck due to touching down when the deck is in its worst condition (stern fully down). Except in the third class (105 knots relative speed) a small additional margin is available for heavier-than-average landings coupled with the worst inclination of the deck. There is reason to believe that, using an aid of this sort, the statistical scatter of impact vertical velocities would be less than is obtained on conventional landings.

On Fig.11, the limitations of this system are shown diagrammatically. It is seen that reduced vertical velocities, or touch-down points nearer the round-down, can only be achieved at the expense of a reduced clearance

over the round-down. Alternatively, additional clearance over the round-down could be obtained, if required in rougher weather, by raising the beam parallel to itself and accepting a touch-down point even farther up the deck, but with no increase in vertical velocity.

Much remains to be done on this problem of presenting the height error information to the pilot (pending fully automatic control) in a form that allows him to give adequate attention to control of airspeed and alignment with the deck. The preliminary tests with a fixed, cheaply-produced mirror on H.M.S. "Illustrious" were sufficiently encouraging to justify the production of a mirror of much higher optical quality with the necessary gyro control gear. Considerable benefit has been derived from an elementary form of airspeed error indicator whose indication is seen reflected in the front windscreen, superimposed on the view of the deck.

The whole problem of conveying three types of information to the pilot, viz, height, alignment and airspeed, is probably capable of a large number of solutions, and much research of a trial-and-error nature will be required to determine the optimum system. The physiological and psychological aspects of the problem are discussed in a recent report[10] issued by the R.A.F. Institute of Aviation Medicine.

6 Conclusions

The development of current deck landing techniques has been discussed with particular reference to those features which are believed to leave room for errors of judgement on the part of the pilot or D.L.C.O. It is suggested that the standard technique as practiced by the Royal Navy (as far as can be ascertained from the brief records available) is probably the optimum form of the conventional "cut-and-flare" technique. Steps should be taken to obtain more up-to-date information on the deck landing technique at present used in Service.

For the future, when the D.L.C.O. is expected to be of less and less assistance to the pilot, there appears to be considerable promise in a much simpler technique which involves neither the "cut" nor the flare, the landing being made off a steady sinking approach defined by a stabilised beam (optical or radio) projected from the deck. Research will be needed to enable the pilot to use this form of assistance while still being free to attend to errors of airspeed and alignment, pending the fully automatic landing. The benefits of this system are, however, obtained at the expense of a touch-down point farther up the deck than is normal, and may aggravate the deck-park problem on a conventional deck.

This technique has an immediate application to the angled deck scheme, where the absence of a safety barrier makes it desirable and possible to leave the engine power on until arresting starts, and where it may be possible to make the normal touch-down point farther up the deck.

As a first step towards the fully automatic landing, this "no-cut, no flare" technique appears to be most encouraging.

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No.	Author	Title, etc.
1	Lean, Duddy and Stott	Seafire Deck Landings on H.M.S. "Pretoria Castle" Investigation of Piloting Technique during Approach. R.A.E. Technical Note No. Aero 1486 July, 1944.
2	-	Trial of Use of U.S. Navy Deck Landing Technique with British Aircraft. Naval Air/Sea Warfare Development Unit and Carrier Trials Unit Report No.505/49 May, 1949.
3	-	Sea Venom NF Mk.20 WK376 (Ghost 3). Initial Deck Landing Trials (by day) 2nd Part Report No. AAEE/868/1 September, 1951.
4	-	Fairey GR17/45 VR546 (Double Mamba). Further Deck Landings. 2nd Part Report No. AAEE/871 December, 1950
5	-	Blackburn GR17/45 WB797 (Double Mamba) Initial Carrier Trials 1st Part Report No. AAEE/864/1 December, 1950.
6	Lean	The Deck-Landing Characteristics of Five Jet-propelled aircraft. R.A.E. Report No. Aero 2465 May, 1952.
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8	-	Carrier Landing System (Phase A). First Interim Report. Project No.PTR AC-210. Flight Test Division, U.S. N.A.T.C. Patuxent River Md. March, 1951.
9	Grimes	"No-cut" Landing Trials on H.M.S. Illustrious. R.A.E. Technical Note No. NA.243 May, 1952
10	Ellis Surgeon Lt.Cdr. RN	Medical Aspects of Naval Aviation, with special reference to Deck Landing. Flying Personnel Research Committee Report No. 798. R.A.F. Institute of Aviation Medicine July, 1952.

Attached:

Tables I and II
Drgs: 27795S to 27805S
Detachable Abstract Cards

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TABLE I

Operational Deck Landings on U.S.S. "Midway" - October 1950

Aircraft	F9F Panther		F8F Bearcat		F4U Corsair	
	Mean	σ	Mean	σ	Mean	σ
Height at "cut", feet	16	4.3	17	4.5	19	3.5
Distance of "cut" aft of round-down, feet	160	41	95	27	95	21
Glide angle at "cut", degs.	2.8	0.9	3.3	1.3	3.9	1.3
Height over round-down, feet	5	2	10	3	9	2
Glide angle at round-down, degs.	5.6	1.5	5.7	1.5	7.4	2.0
Distance of touch-down forward of round-down, feet	48	17	96	20	77	19
Total distance, "cut" to contact, feet	208	47	191	41	172	26
Glide angle at touch-down, degs.	6.3	2.5	5.6	1.6	7.1	1.9

Note:- σ = standard deviation about the mean.

TABLE II

Deck Landing Trials on H.M.S. "Illustrious" - Comparison of Standard and Modified Techniques

Aircraft Type	Attacker F1		Blackburn GR17/45				Fairey GR17/45				Sea Venom Mk.20					
	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Weight, lb	10,500		16,100		16,000		16,000		15,700		10,300		10,700		10,500	
Wind Speed, kts.	42		33		34		31		32		38		40		40	
Technique	Standard		Standard		Modified		Standard		Modified		Standard		Standard		Modified	
CG Position	Normal		Forward		Forward		Forward		Forward		Aft		Forward		Forward	
"Cut" Height, ft	N.R.		N.R.		N.R.		N.R.		N.R.		15	2.7	15	3.5	13	3.1
"Cut" distance, feet aft	N.R.		N.R.		N.R.		N.R.		N.R.		105	31	110	34	35	33
Glide angle at "cut", degs.	N.R.		N.R.		N.R.		N.R.		N.R.		3.5	0.7	3.5	1.0	5.4	0.8
Approach airspeed, kts	106	3.0	89	3.7	90	1.3	87	2.8	85	3.2	109	3.4	113	4.5	109	3.5
Height at round-down, ft	10	1.9	10	1.6	10	2.0	9	2.4	9	1.2	8	2.4	7	2.2	10	2.3
Touch-down point, ft forward	108	22	101	17	108	17	82	25	98	14	82	21	83	17	87	20
"Cut"- contact distance, ft	N.R.		N.R.		N.R.		N.R.		N.R.		187	34	193	33	122	28
Impact Vertical Velocity ft/sec (Main Wheels)	9.1	2.0	8.2	2.1	7.2	1.8	9.4	2.0	6.3	1.3	11.8	2.3	12.7	1.7	11.6	2.7
Impact Vertical Velocity ft/sec (Nose or tail wheel)	10.9	3.4	7.4	1.8	6.7	1.2	8.2	1.9	6.5	1.0	12.2	2.1	11.9	1.4	12.0	1.9
Attitude at touch-down degs, nose-up from 3-point	-2.6	1.6	7.5	2.1	7.1	1.9	3.6	1.6	3.9	1.3	3.1	1.6	2.5	1.5	1.6	1.2
Mean Vertical Velocity over deck, ft/sec	10.5	1.7	9.4	2.2	8.8	1.4	9.9	1.2	8.0	1.5	11.4	1.9	10.7	2.5	13.1	3.4

Note:- σ = standard deviation about the mean.

27796 S.

FIG.1.

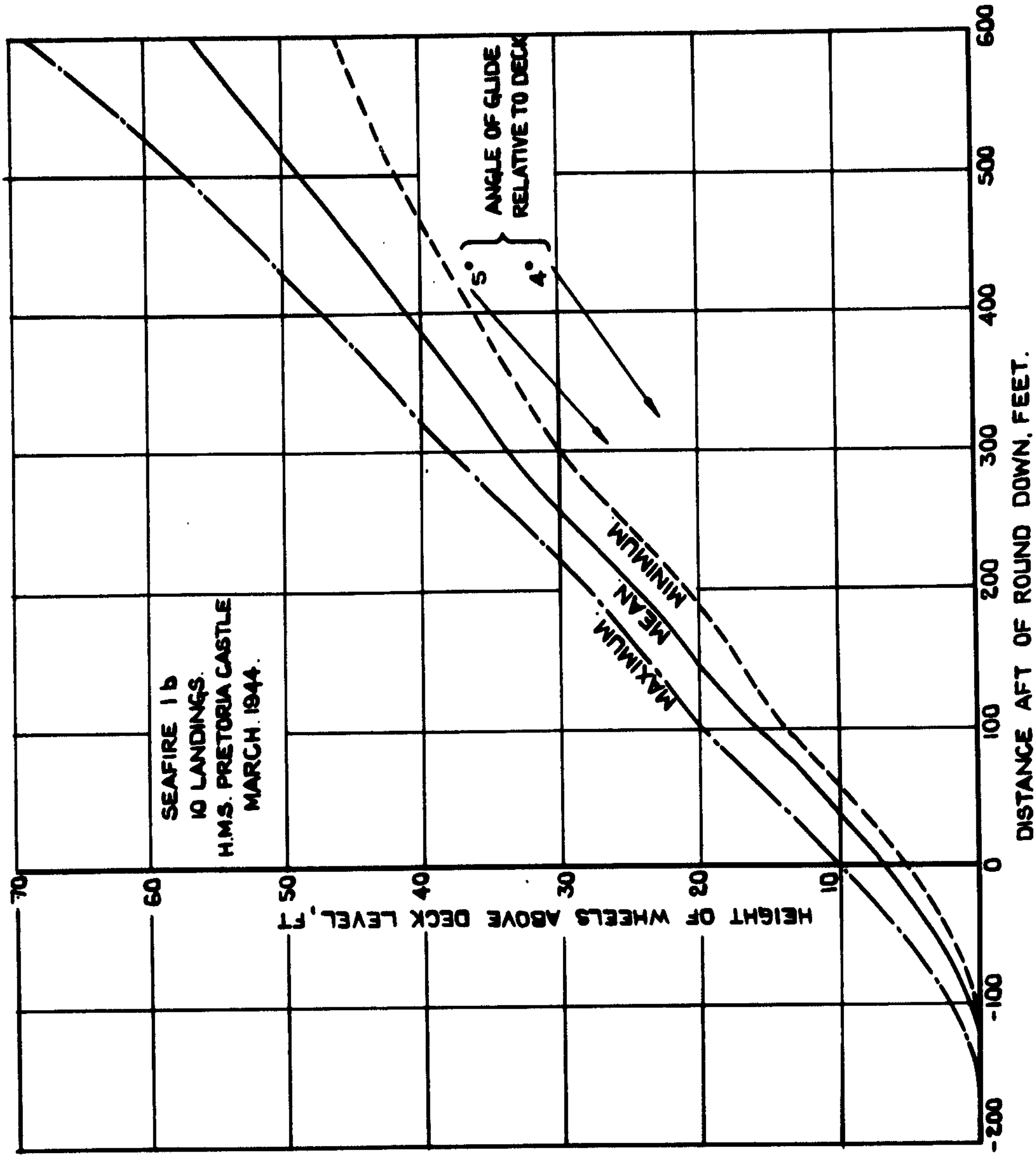


FIG.1. DECK-LANDING TECHNIQUE. PRE - 1949.

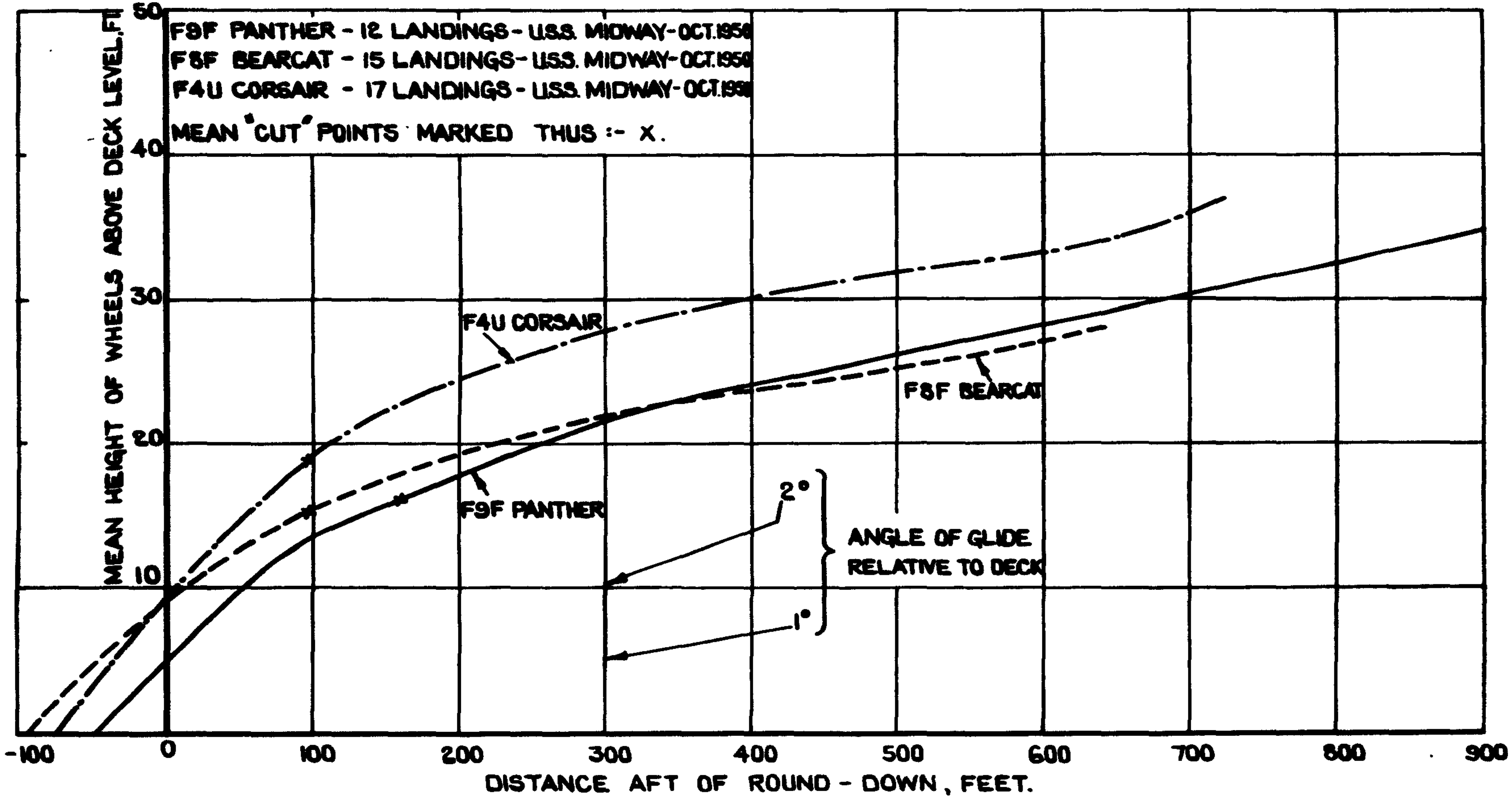


FIG. 2. U.S. NAVY-STANDARD DECK LANDING TECHNIQUE.

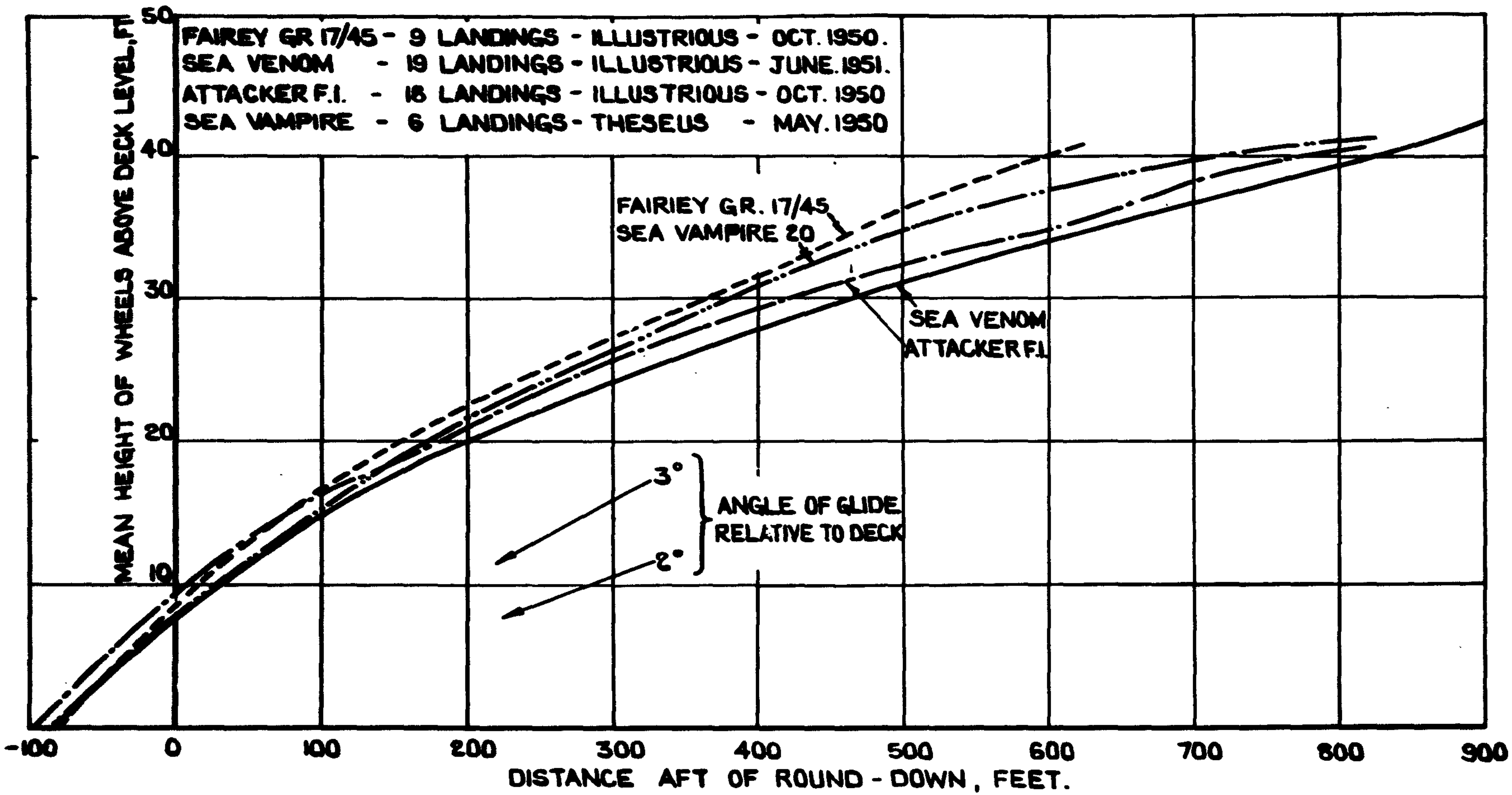


FIG. 3. STANDARD DECK LANDING TECHNIQUE - ROYAL NAVY.

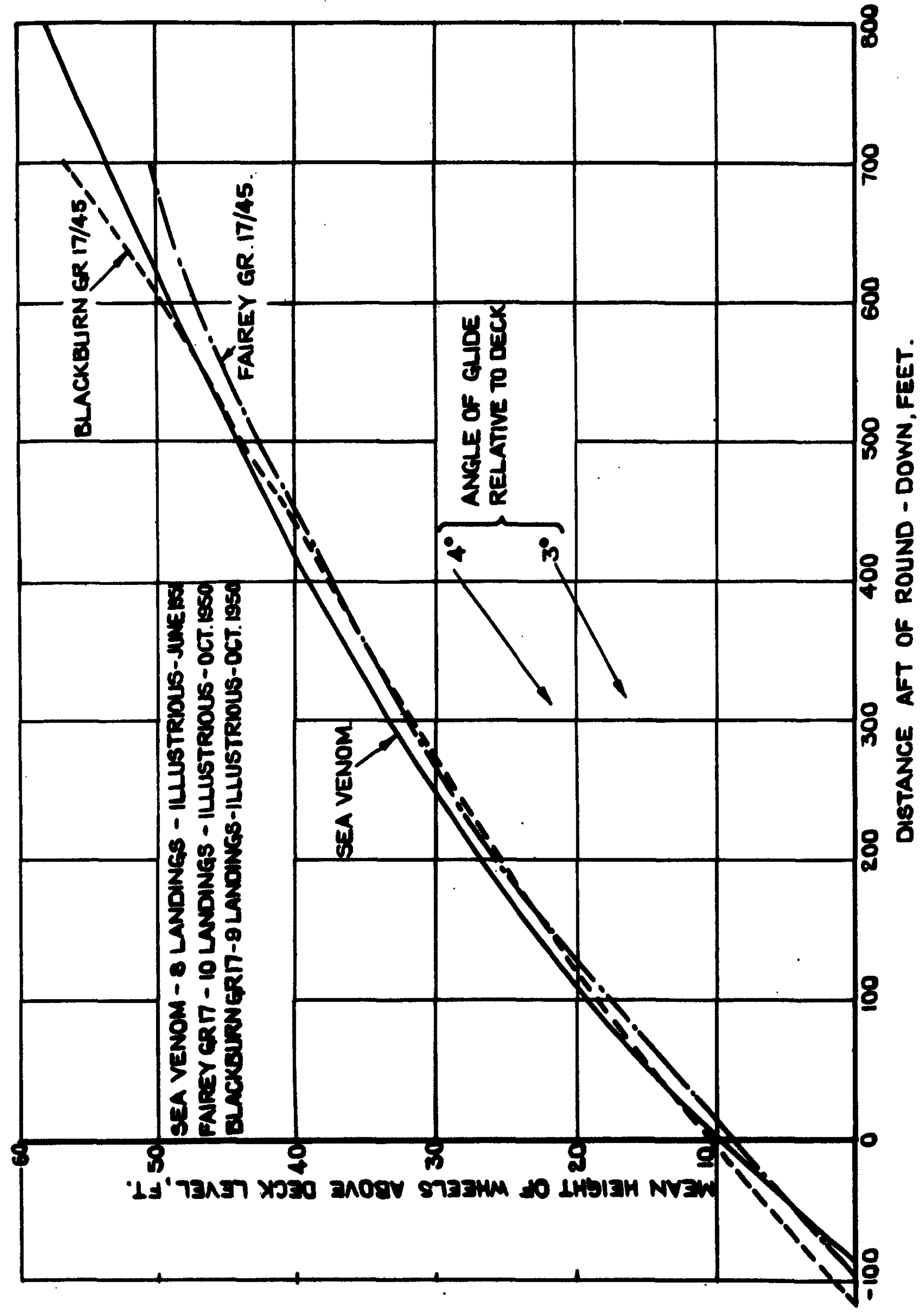


FIG. 4. MODIFIED STANDARD DECK LANDING TECHNIQUE – A&AEE.

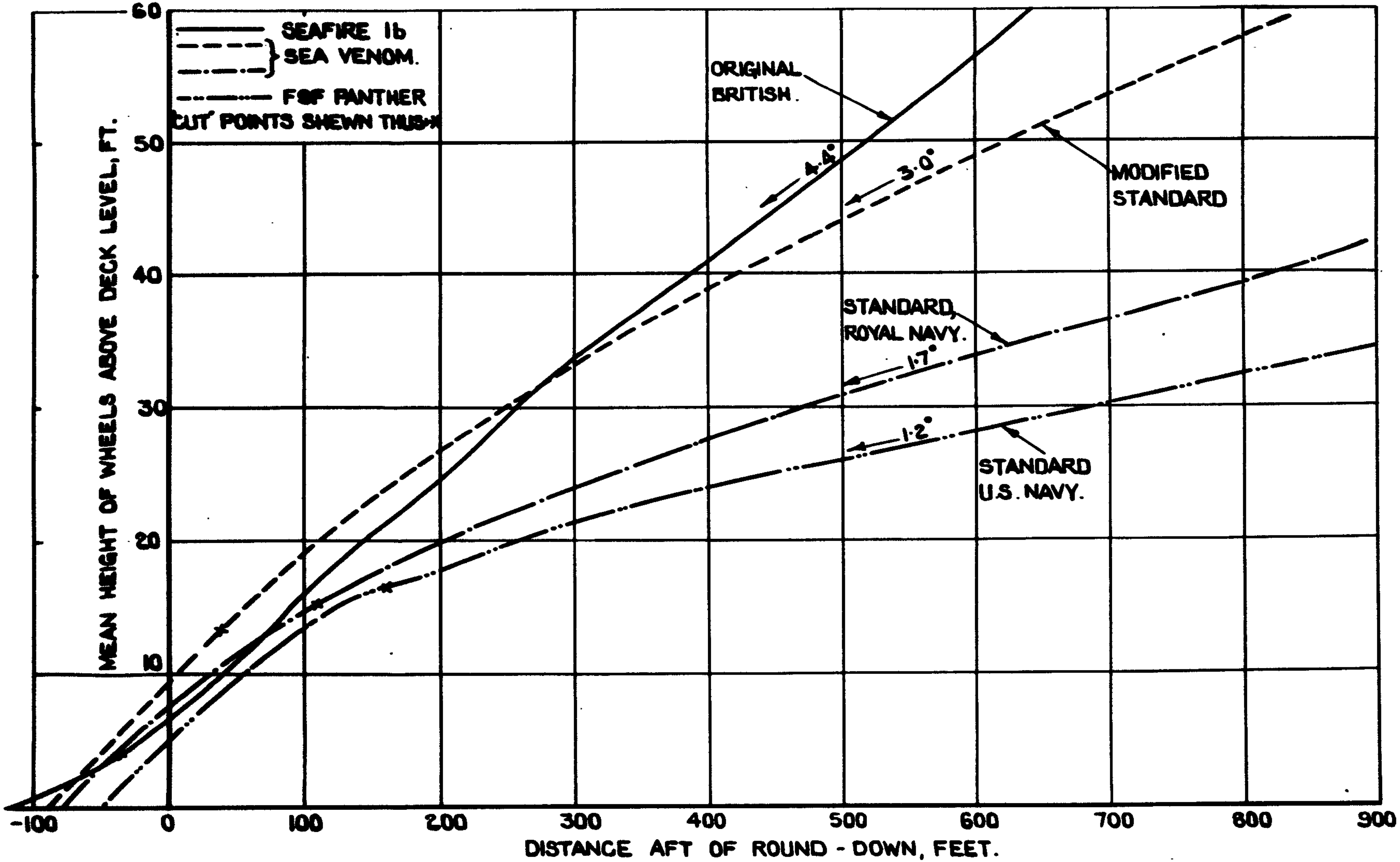
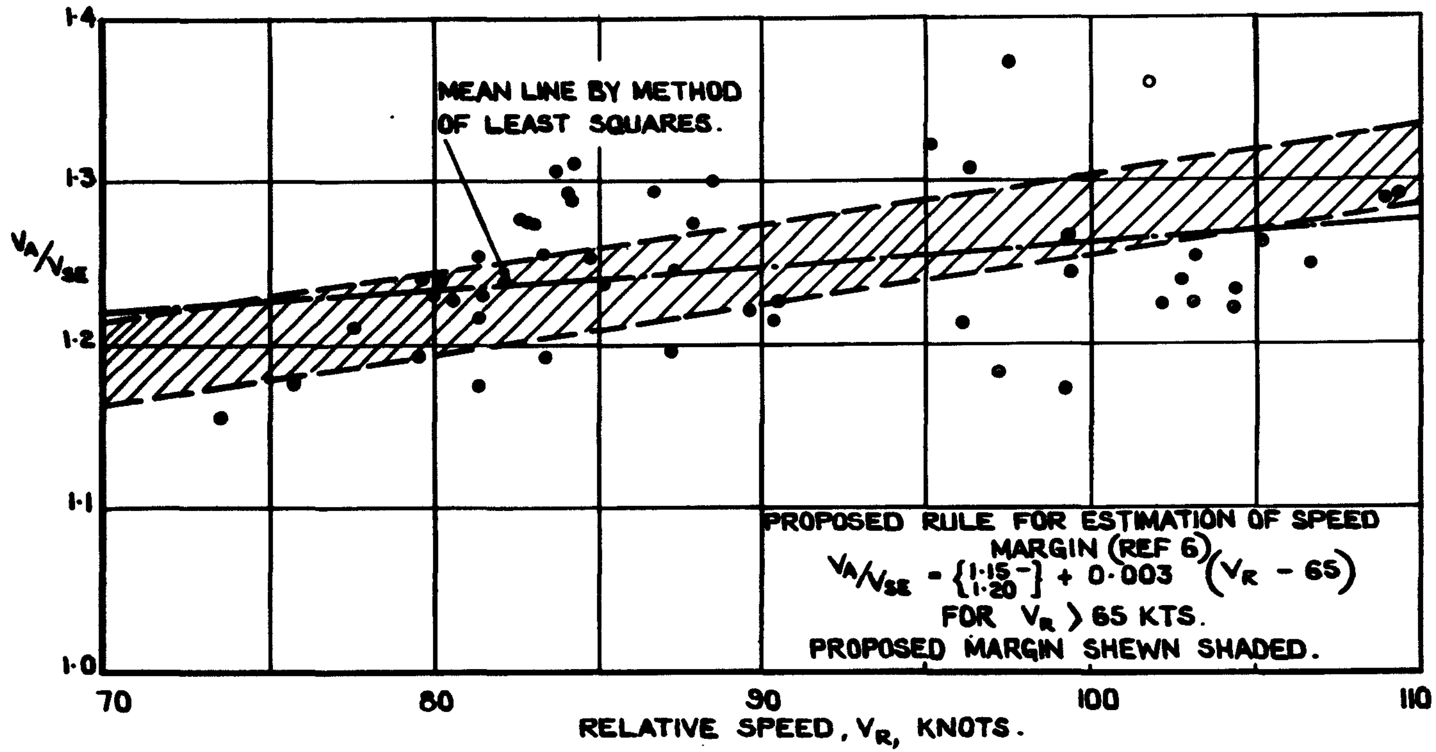


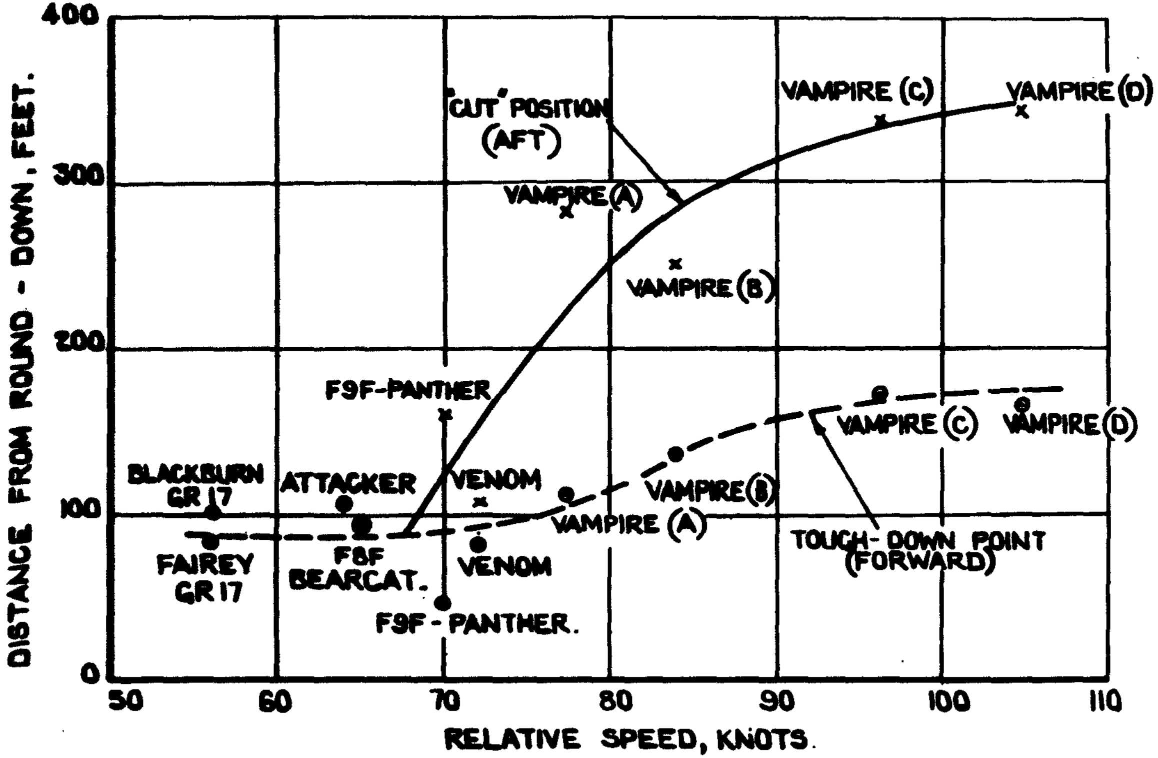
FIG.5. COMPARISON OF DECK-LANDING TECHNIQUES.



VAMPIRE MK. 20.

RESULTS OF HIGH CLOSING SPEED TRIALS.

FIG. 6. VARIATION OF SPEED MARGIN WITH RELATIVE SPEED.



NOTES.

—x— 'CUT' POSITION

- -⊙- - TOUCHDOWN POINT.

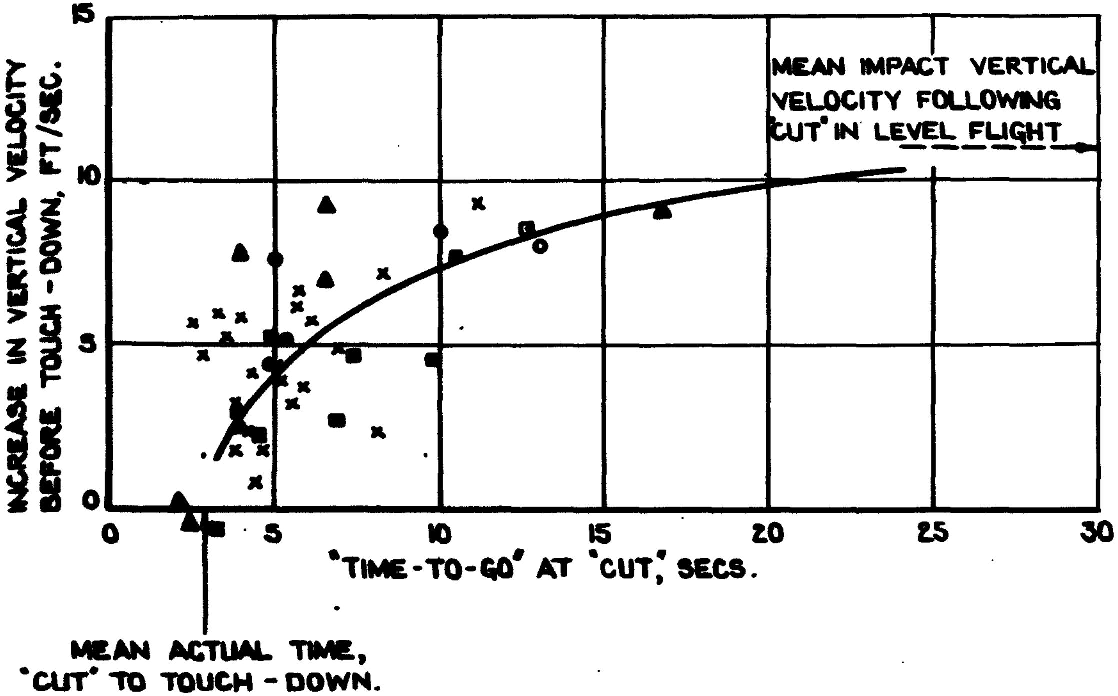
VAMPIRE (A) 70 - 80 KTS. REL. SPEED.
(B) 80 - 90 KTS. REL. SPEED.
(C) 90 - 100 KTS. REL. SPEED.
(D) 100 - 110 KTS. REL. SPEED

RELATIVE SPEEDS FOR F9F - PANTHER & F8F - BEARCAT ARE APPROXIMATE.

'CUT' POSITIONS FOR BLACKBURN AND FAIREY GR 17, & ATTACKER WERE NOT RECORDED.

FIG. 7. EFFECT OF INCREASED RELATIVE SPEED ON FINAL PHASE.

FIG. 8.



CODE:-
ʘ RELATIVE SPEED 70-80 KTS.
x RELATIVE SPEED 80-90 KTS.
⊟ RELATIVE SPEED 90-100 KTS.
Δ RELATIVE SPEED 100-110 KTS.

NOTE:- RATIO OF HEIGHT AT 'CUT' TO INSTANTANEOUS VERTICAL VELOCITY AT 'CUT' IS THE 'TIME-TO-GO' BEFORE TOUCH-DOWN.

SEA VAMPIRE MK. 20.
H.M.S. ILLUSTRIOUS. JUNE. 1951.

FIG. 8. EFFECT OF FLIGHT CONDITION AT 'CUT' ON THE 'POST-CUT' MANOEUVRE

FIG. 9.

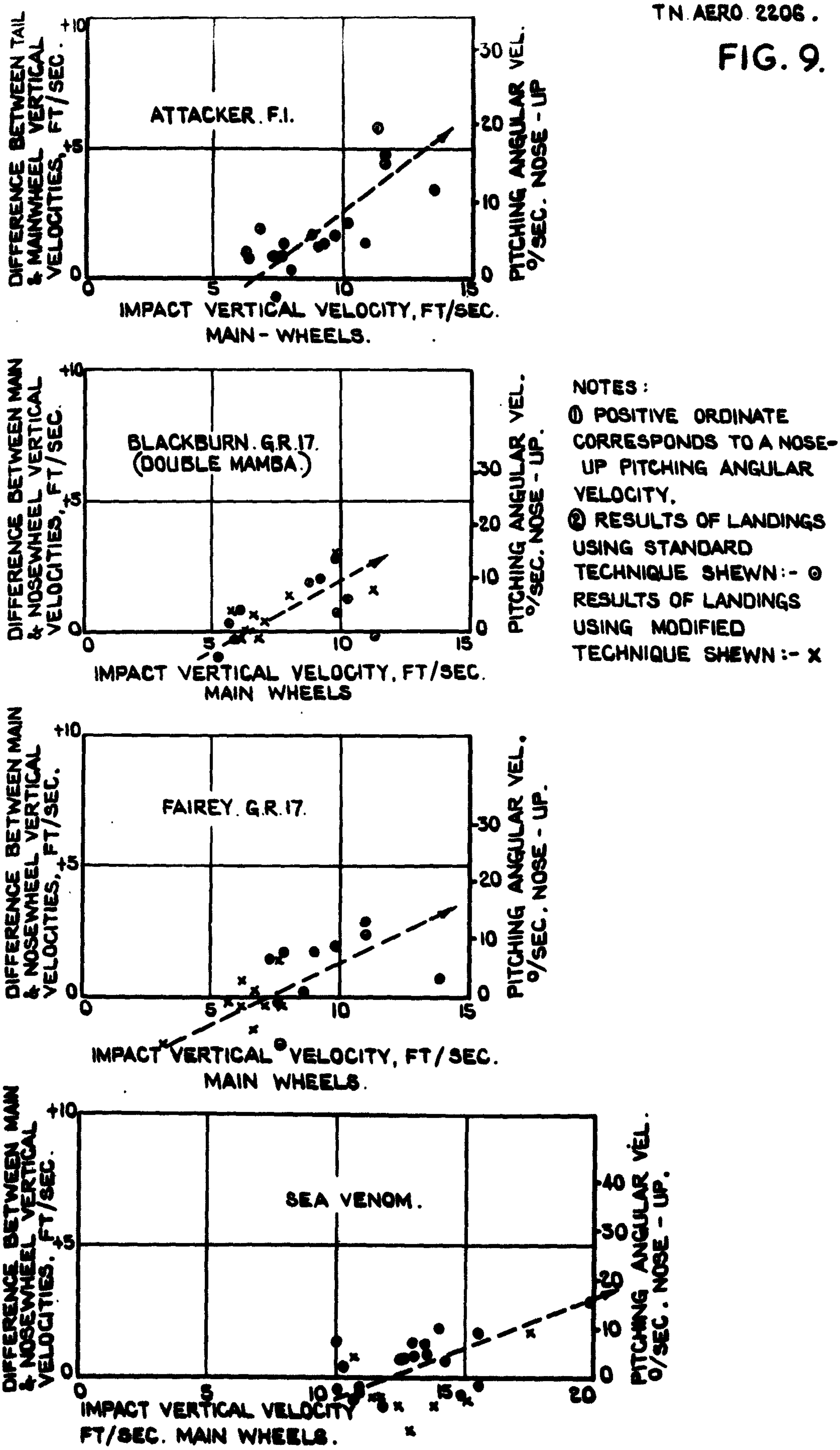


FIG. 9. RELATION BETWEEN PITCHING MOTION AT TOUCH-DOWN & IMPACT VERTICAL VELOCITY.

FIG. 10.

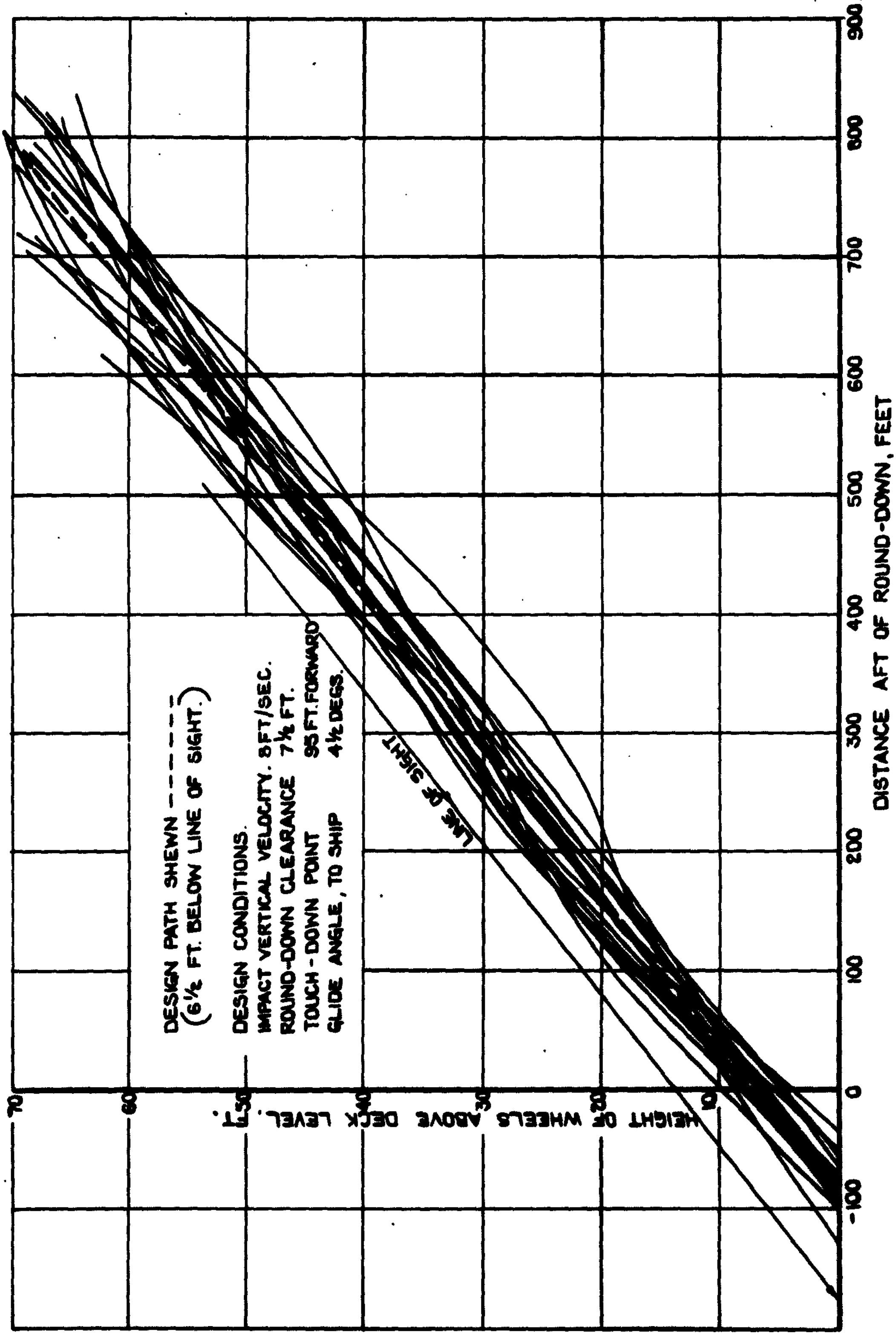
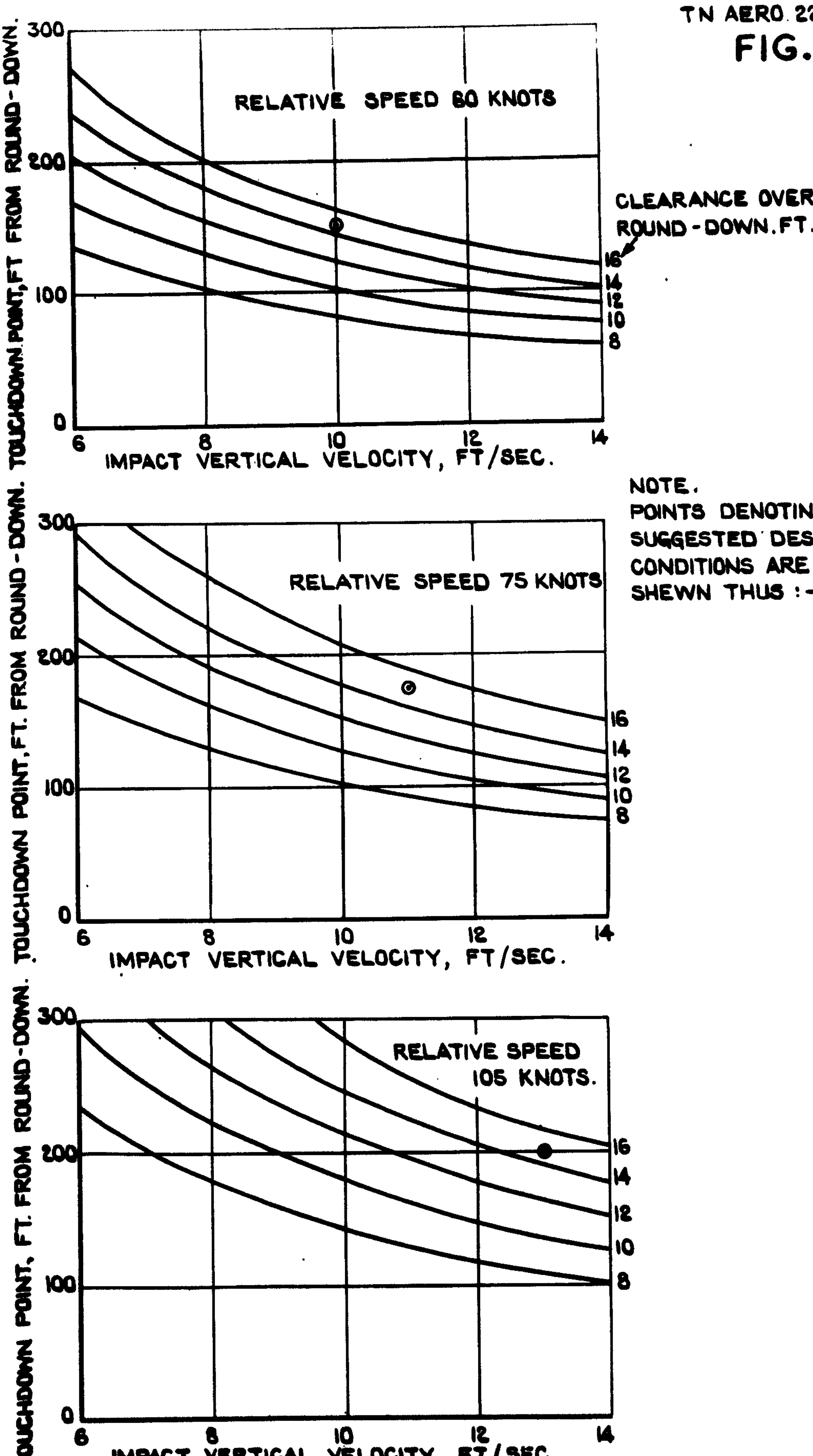


FIG. 10. SEA VAMPIRE MK. 20 - 'NO-CUT, NO-FLARE' TECHNIQUE.



NOTE.
POINTS DENOTING SUGGESTED DESIGN CONDITIONS ARE SHEWN THUS :- ⊙

FIG. 11. "NO-CUT, NO-FLARE" TECHNIQUE - TOUCHDOWN LIMITATIONS.

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1952.11 533.6.015.2:
Lean, D. 629.139.812:
533.652.1.011.3(42) and (73)

A REVIEW OF CURRENT DECK LANDING TECHNIQUES

Information on current deck landing techniques is collected and analysed. Particular attention is directed towards those features of the various techniques which are believed to leave room for errors of judgement. It is suggested that the so-called standard technique, as interpreted by the Royal Navy, is the optimum for present-day carrier-borne aircraft, pending a more radical change in technique.

Preliminary tests with a much simpler technique, eliminating precise last-minute control movements and requiring no Deck Landing Control officer, are sufficiently encouraging to recommend this technique as being a suitable first step towards the fully automatic landing.

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